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DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

AERONAUTICAL RESEARCH LABORATORY

MELBOURNE, VICTORIA

Aircraft Structures Technical Memorandum 571

F/A-18 STABILATOR:

EQUIVALENT SET OF POINT FORCES REQUIRED FOR PNEUMATIC BAG LOAD CASE SIMULATION

by

Simon C. D'Arcy

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SUMMARY

In preparation for a fatigue test on the F/A-18 rear empennage, a method has been developed to determine actuator loads for the horizontal stabilators. A computer program called STABAG has been written which implements the method to enable automated computation of actuator loads corresponding to input spectrum points. This report describes the program and serves as an operating manual for it.

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1. INTRODUCTION

In preparation for a fatigue test on the F/A-18 rear empennage, a method has been developed to determine actuator loads for the horizontal stabilators. A computer program called STABAG has been written which implements the method to enable automated computation of actuator loads corresponding to input spectrum points. This report describes the program and serves as an operating manual for it.

The actuator loads covered in this report are for an array of pneumatic bag actuators which will apply the manoeuvre loading in the fatigue test. Dynamic loading applied by hydraulic or electromagnetic shakers is not covered here.

The actuator loads are calculated from input root conditions and input spanwise distributions of shear force, bending moment, and torsion. The selection of the most appropriate spanwise distributions from a data bank covering the aircraft flight envelope could be automated based on the aircraft parameters but this is not a current feature of the program.

One limitation of the F/A-18 fatigue test is that the stabilators will be locked at one fixed angle, whereas in flight they are all-moving control surfaces through the angular range 10.5^0 leading edge up to 24^0 leading edge down. The resulting angular mismatch between the test and flight for many of the spectrum points makes it impossible to get right both the spanwise loading on the stabilator and the root values transmitted to the fuselage. Under these circumstances there is a step difference between the stabilator root conditions from the spanwise loading of the stabilator and the stabilator root conditions necessary to get the fuselage loading right. The root values transmitted to the fuselage are regarded as being of paramount importance and the spanwise loading of secondary importance. The approach adopted is then to determine loads which generate exactly the right root conditions for the fuselage while approximating the spanwise loading of the stabilator as closely as possible. A special algorithm was developed to achieve this and is described in the report.

The Imperial system of units is generally used throughout this report because all F/A-18 data is in that system.

2. OVERVIEW OF PROGRAM STABAG

The basic function of the program is to determine a set of point forces at prescribed locations on the stabilator which closely simulates prescribed spanwise distributions of shear force, bending moment, and torsion. As well, prescribed root values of these quantities are exactly generated.

The number and position of these point forces are specified by the user, as are the above mentioned root conditions. The spanwise distributions are selected from a data bank of load cases held in external files.

After the point forces are calculated, the corresponding shear force, bending moment, and torsion diagrams can be drawn and compared to other such diagrams, including those found from the distributions being simulated and from other sources read in from an external file.

A numerical comparison of shear force, bending moment, and torsion at the given point force positions can also be made, showing the percentage differences. This can be done between different calculated distributions or with other distributions read in from an external file.

The program STABAG has been written in Pascal using Borland Turbo Pascal version 5.5. The program structure consists of a 'main program' and ten subroutines (termed procedures in Pascal). The main program holds the Main Menu that lists the user's operational options. Each option basically corresponds to a procedure. Each procedure carries out a specific task either asking for data from the user or calling it from external data files, or performing calculations required and outputting the results. (To view the written coded program refer to APPENDIX 1.)

3. OVERVIEW OF STABILATOR SET UP

3.1 Structural Description

The F/A-18 utilizes two independent horizontal stabilator surfaces which are entirely moveable. These surfaces may be actuated differentially, for roll control, or collectively for longitudinal trim and pitch control. Detailed horizontal stabilator structural arrangement is presented in FIGURE 1.

The stabilator surfaces have symmetrical aerofoil sections with a surface area of 44 ft^2 (4.1 m^2) per side, and aspect ratio of 2.44, and an anhedral of 2^0. The symmetrical aerofoil offers the advantage of interchangeability; that is, the capability of any assembly being used on either side of the aircraft.

The structure of the horizontal stabilator shown in FIGURE 1 consists of Ti-6A1-4V inboard and outboard ribs, forward and aft well beams and spars, full depth 5056-H39 aluminium honeycomb core, and AS/3501-6 graphite/epoxy skins bonded to Ti-6A1-4V splice plates. The graphite/epoxy skins consist of multiple plies with the number of plies and their fibre orientation optimized such that adequate strength and stiffness are achieved. The skins are stabilized by full depth aluminium honeycomb core which provides the shear load path.

The horizontal stabilator position is controlled by a hydraulic actuator that drives a machined Ti-6A1-4V drive horn which is attached to the root rib. Each stabilator is supported on a steel spindle via two self-aligning aluminium pivot bearings with teflon linings. Anti-fret bushings of beryllium copper are located between the bearing outer race and titanium rib housing. The stabilator is designed to be removable from the spindle to facilitate inspection or replacement. The leading edge as well as the aft section of the tip are replaceable and the centre section of the tip is interchangeable for easy maintenance.

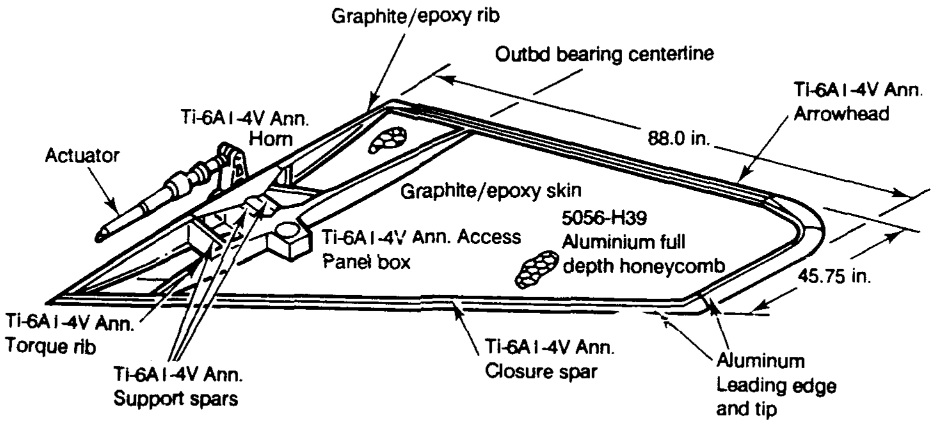


FIGURE 1. HORIZONTAL STABILATOR STRUCTURE

3.2 Pneumatic Bag Set Up and Coordinate System

The point forces found in this program represent a simple model of the loading produced by an array of pneumatic bags which realistically give pressures over circular areas. In this program only the point forces will be referred to, with the assumption that the user will convert these forces to the required pressure for the pneumatic bag area used. The point force positions will mostly be called the 'bag positions'.

The user determines the number of bags to be used and their relevant positions using the coordinate system specified by the program as follows: the origin is the leading edge root position of the stabilator, positive 'Y' is aftwards, normal to the stabilator spindle axis and in the stabilator neutral plane and positive 'X' is towards the stabilator tip parallel to the spindle axis. The units for both axes are inches, in keeping with the origin of the data. (The user is reminded of this coordinate system whilst working the program when inputting the bag positions, refer to FIGURE 2)

It is important to note that the shear forces, bending moments, and torsions calculated in this program have been taken relative to the stabilator spindle axis. This is especially important when comparing diagrams found by other means.

For the ability to easily calculate and match a given root torsion condition it is assumed that the first and last numbered bags have the same X-position, and they should also lie either side of the spindle axis. The program automatically sets the X-position of the last numbered bag the same as the first to remind the user that this must be the case. (Refer to FIGURE 2)

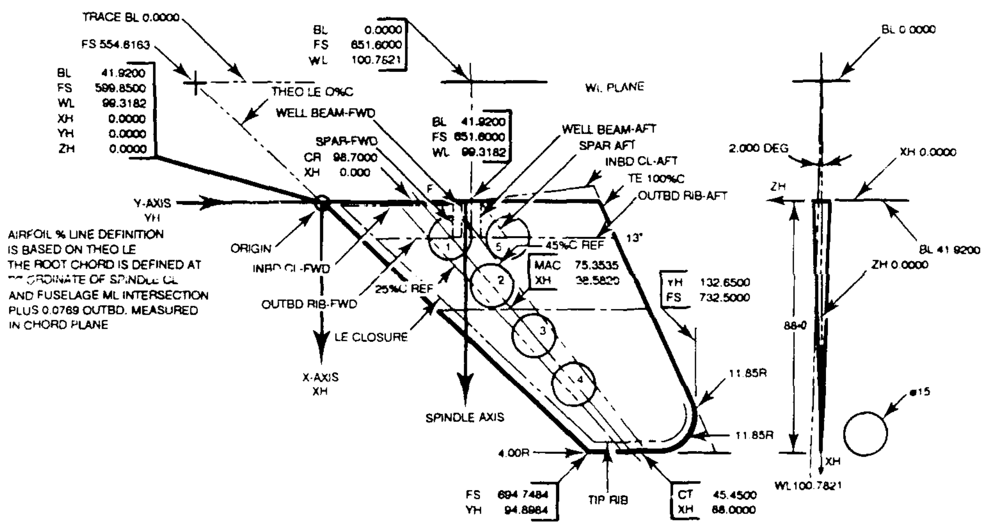


FIGURE 2. F-18 HORIZONTAL STABILATOR DEFINITION

4. DESCRIPTION OF METHOD

4.1 Calculating the Bag Forces

The method looks at the profiles of the *desirable* bending moment and torsion diagrams. It then aims to match these profiles when calculating the bag forces. But this 'matching' is dependent upon the shear/bending/torsion root values set by the user <u>and</u> the number of bags used and their positions on the stabilator.

Starting from the outermost spanwise bag position and working inboard, the difference between the desirable profile values and the actual values at each bag position is minimised and the resulting equations are solved for the corresponding bag forces (F). The three innermost bags are solved for last, using the root condition equations and the now known outer bag forces.

For the following detailed description of this method a system of five bags is looked at where the first and fifth bag have the same spanwise (X-axis) position. (Refer to FIGURE 2)

The actual bending moment (M) and torsion (T) values at the second outermost bag position (#3) are dependent on the bag positions #3 and #4, viz.

$$M_3^A = F_4(x_4 - x_3)$$

$$T_3^A = F_4 y_4$$

The shear force (S) profile values are not used in this matching procedure. Since the shear force profile is dependent on the bending moment and torsion profiles then the calculated shear force profile is matched automatically.

The *desirable* bending moment and torsion values are . . .

$$M_3^D = M_3^P$$

$$T_3^D = (T_3^P + T_4^P)/2$$

A = actual
D = desirable
P = profile

To minimise the error between the actual and desirable values, the Least Squares Method is used which in this case results in an equation for the outermost bag force (bag force #4). (See the calculations in APPENDIX 2)

Now, knowing the outermost bag force, in terms of the profile values at the bag positions, the next bag force along can be calculated in the same manner, and so on. Finally the inner bag forces can be calculated using the now known values of the outer bag forces and the prescribed shear(S)/bending(M)/torsion(T) root values, viz.

$$S_R = (F_1 + F_5) + F_2 + F_3 + F_4$$

$$M_R = (F_1 + F_5)x_1 + F_2x_2 + F_3x_3 + F_4x_4$$

$$T_R = F_1y_1 + F_2y_2 + F_3y_3 + F_4y_4 + F_5y_5$$

For a system of five bags only the outer two (#3 and #4) are calculated using the Least Squares Method whilst the remaining three bags (#1, #5, and #2) are found using the above root equations. (See APPENDIX 1 for the calculations for a five bag system.)

The program is not limited to calculating for five bags only, it can be used for between 2 and 10 bags.

4.2 Interpolating Profile Data

As described in SECTION 4.1, shear force, bending moment, and torsion profile data for the stabilator are called from external data files. In Section 5.6 those same data are called when comparisons between those externally found profiles and STABAG calculated models are made.

In either case the actual bag positions generally do not coincide with any of the external data profile points (Refer to SECTION 5.8). So there is a simple interpolation technique used whenever an external data profile value is needed corresponding to a specific spanwise bag position.

This technique firstly calls up an external data file specified by the user. It then looks at each given bag position listed in this file and determines between which two spanwise position values (0,10,20,30,40,50,60,70,80, or 88 - measured in inches) the wanted profile point lies. Each of these spanwise positions has corresponding shear/bending/torsion characteristics and a linear interpolation is used to find estimates of the wanted profile values. (See FIGURE 3)

$$\text{eg: } Y_{66} = Y_{60} + \left[\frac{X_{66} - X_{60}}{X_{70} - X_{60}}\right] [Y_{70} - Y_{60}]$$

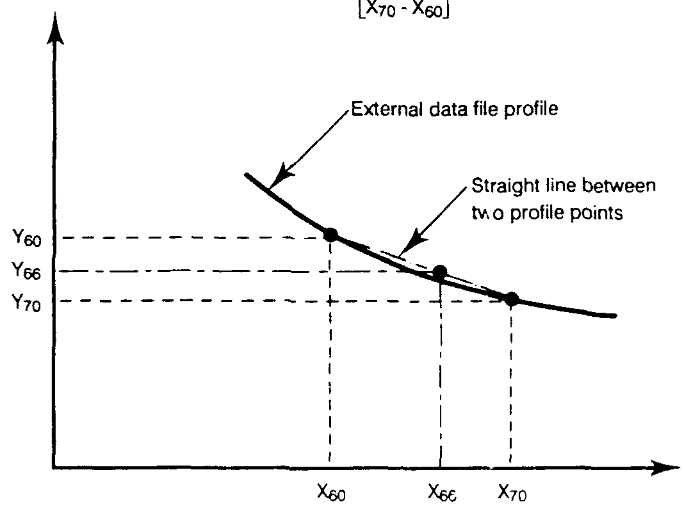


FIGURE 3. STRAIGHT LINE INTERPOLATION METHOD

5. DETAILED DESCRIPTION OF PROGRAM AND OPERATING INSTRUCTIONS

In the sections below the program is described in detail through the menu structure. A sequence of related screen frames tracing a typical run sequence can be followed through in APPENDIX 2 in parallel with the description.

5.1 The Main Menu

0: EXIT
1: Input New Bag Coordinates
2: Input New Root Conditions
3: Calculate and Table Forces
4: Graph Shear, Bending, Torsion
5: Compare Shear, Bending, Torsion

The Main Menu gives six choices, the first of which is to exit the program. It is necessary to note that before being able to draw any of the program calculated diagrams or make comparisons using such data, the calculation of point forces must be done and, to do this, bag coordinates and root conditions must be set up and the shear force, bending moment, and torsion profiles chosen. In fact, this order of events is the same as that given in the Main Menu. If the user wishes only to draw diagrams and compare data from external sources then this can be done at any stage.

Up to ten sets of bag coordinates, ten sets of root conditions and ten sets of spanwise profiles may be set up, and then bag forces calculated and corresponding shear/bending/torsion profiles may be drawn or compared. Up to 10 sets of shear/bending/torsion diagrams may be called from external files and drawn.

EXIT

By entering '0' from the Main Menu the program is terminated.

5.2 Input New Bag Coordinates

By entering '1' from the Main Menu the Bag Coordinates Set Up procedure appears on the screen. This is where the user states the number and position of the pneumatic bags to be used. The first prompt asks the user to number the Bag Coordinate

External File Number to be called. This data file must be of the form COORD_x.DAT. The user must enter the 'x' value where only integers from 0-9 are usable.

The second prompt asks for the number of bags to be used. An arrangement of up to 10 bags can be calculated (Refer to SECTION 5.3).

The program next reads in the coordinates of the bags and at this point there is a reminder of the coordinate system (as described in SECTION 3.2). But first a third prompt asks if the user would like to change the number of bags to be used. Entering '1' means a change is required and the program will then return to that stage of the bag coordinate input procedure. Entering '0' means that no change is required and then a list of bag numbers and coordinates is automatically read in from the external file COORD_x.DAT.

If this list is incorrect then the user can enter each bag number to be changed and manually input the corresponding "X" and "Y" values, else entering '0' will complete the bag coordinate input procedure and the screen will return to the Main Menu.

The benefit of having the coordinates already set up in the external file is to save time when using the same bag coordinates and running the program repeatedly.

5.3 Input New Root Conditions

By entering '2' from the Main Menu the Root Conditions Set Up procedure appears on the screen. This is where the user states the root shear force, root bending moment and root torsion conditions to be met.

The first prompt asks the user to name the Bag Coordinate External File Number that is to be used with the root conditions about to be inputted, as set up in SECTION 5.2. Only integers from 0-9 are usable.

The program then automatically lists the three root condition values as read in from the external file ROOTF_x.DAT. The root condition data are in Imperial units of *lbf* and *in.lbf*. If a change is required then the user can input the digits '1' to '4' corresponding to the value to be changed (See APPENDIX 3). The new value can then be inputted.

When no changes are required entering '0' will complete the Root Conditions Set Up procedure and the screen will return to the Main Menu.

5.4 Calculate and List Bag Forces

By entering '3' from the Main Menu the Calculation and Listing of Bag Forces procedure appears on the screen. This is where the user instructs the program to actually calculate and list the bag forces for the predefined bag coordinates and root conditions.

The first two prompts ask the user to name the Bag Coordinate External File Number and the Root Conditions External File Number that are to be used for the current calculations. Only integers from 0-9 are usable. These files must have previously been called as per SECTION 5.2 and SECTION 5.3 respectively.

The next prompt asks which External Profile Data File (of the form FA18_x.DAT) is to be used. At this prompt only the corresponding 'x'-integer needs to be inputted and only the integers 0-9 are usable. (Refer to SECTION 5.8)

The program then calculates and lists the force required for each bag so as to match the given root conditions and the shear force, bending moment, and torsion profiles.

The last prompt gives the option of calculating and listing another set of bag forces (for other predefined conditions) or for returning to the Main Menu. By entering '1' the program returns to the beginning of the Calculate and List Bag Forces procedure without erasing any previous bag-force lists. By entering '0' the screen returns to the Main Menu.

5.5 Graph Shear, Bending, & Torsion

By entering '4' from the Main Menu the Shear Force, Bending Moment, and Torsion Diagrams procedure appears on the screen. This is where the user can draw up to five different sets of shear/bending/torsion diagrams for comparison and/or 'visualisation'. The program can graph the diagrams from the set ups calculated or from an external file (FA18_x.DAT) where the profiles are listed. (See SECTION 5.8)

The first prompt is the Graph Main Menu and it gives the user three options: EXIT, draw a graph of a STABAG calculated set up, or draw a graph from an external file.

By entering '0' from the Graph Main Menu the screen returns to the Main Menu.

By entering '1' from the Graph Main Menu the program will proceed to draw the shear/bending/torsion diagrams corresponding to a calculated Bag Coordinate and Root Conditions Set Up. The first two prompts ask the user for the Bag Coordinate and Root

Condition External File Numbers that were used in the STABAG calculations in SECTION 5.4. The program recalls the calculated bag forces found using the Bag Coordinate and Root Conditions Set Up just inputted. It then draws the corresponding shear/bending/torsion diagrams and the Graph Main Menu is returned.

By entering '2' from the Graph Main Menu the program will proceed to draw the shear/bending/torsion diagrams from an external file that contains the appropriate profile points. The prompt that replaces the Graph Main Menu asks the user to nominate which external file to call from. The external profile data files used in this procedure are in the following format: FA18_x.DAT where 'x' is an integer from 0-9. At the prompt only the corresponding 'x'-integer needs to be inputted. When this is done the corresponding shear/bending/torsion diagrams are automatically drawn and the Graph Main Menu is returned.

Note that no diagrams are deleted, but instead super imposed on the same axes, until a return to the Main Menu is made. It is possible to compare up to five sets of diagrams on the one graph with each set having a different line style. A key to the graph is automatically drawn below the graph heading showing line style, the root conditions, and the profile followed. For the diagrams drawn from external files the key lists those files by name.

By entering '0' from the Graph Main Menu the screen returns to the Main Menu.

5.6 Compare Shear, Bending, & Torsion

By entering '5' from the Main Menu the Comparison of Shear Force, Bending Moment, and Torsion (at the bag positions) procedure appears on the screen. This is where the user can compare the specific shear/bending/torsion values at the bag locations of two models. The models used can be the program's calculated 'set-ups' or from another source where the data are found in an external file of the form FA18_x.DAT ('x' can be an integer from 0-9). (See SECTION 5.8)

The first prompt that appears on the screen asks the user to nominate whether the first model to be compared is one calculated by the program or from an external file. By entering '1' the first model to be compared is a program calculated set-up and prompts ask the user to name by number the Bag Coordinate and the Root Condition External File Numbers used. If '2' is entered instead, then the first model to be compared is from an external file and the only prompt that appears is for the 'x'-value of the external file (FA18_x.DAT) as described above.

The next prompt asks the user to nominate whether the second model to be compared is one calculated by the program or from an external file. The options that can be taken are the same as for the first model to be compared as seen above.

Following this, the program lists the bag numbers and their spanwise position, the shear force, bending moment, and torsion values at these positions, and the percentage difference of the two values relative to the second model.

The final prompt gives the choice of exiting or listing another comparison. By entering '0' at this prompt the screen returns to the Main Menu. By entering '1' the comparison procedure is begun again as described above.

5.7 Hardcopy Output

There are two types of screen output displays seen whilst running STABAG; text-based and graphics-based. The graphics-based output display is used in only two circumstances, the first being the initial title of the program - the very first screen output display seen. This display is seen only once when running the program. The second graphics-based output display is that referred to in SECTION 5.5, where the shear force, bending moment, and torsion diagrams are drawn.

For a hardcopy of the text-based screen output display the user need only perform the simple 'print screen' function as found on all IBM compatible PS/2 style personal computers, assuming a printer is attached. This will not work for the graphics-based output displays.

For a hardcopy of the graphics-based screen output display the user must have running concurrently with STABAG a 'screen freezing' program. With such a system in place any screen output display seen whilst running STABAG can be 'frozen' at any time and stored or printed. The actual process of storing/printing is dependent upon the 'screen freezing' program used. (One such program available at the Aeronautical Research Laboratory, and which does the job very well, is PIZAZZ PLUS^{tm} by Application Techniques, Inc.)

5.8 Use of External Files

STABAG makes use of external data files as well as the Turbo Pascal files that the normal running of the program calls up. These data files are used to decrease the user time when actually running the program, as they can store much of the data requested by the program. They are also used to store the profiles of the shear/bending/torsion diagrams found by sources other than this program, such as data recorded in actual flight, etc.

There are three types of data files used:

COORD_x.DAT
ROOTF_x.DAT
FA18_x.DAT

where 'x' can be an integer in the range 0-9.

(See APPENDIX 4 for example listings of these three external files.)

COORD_x.DAT

These files store the coordinates of the centre-points of the pneumatic bags. Up to ten sets of coordinate data may be stored externally ready to be called by the program. The axes for these coordinates are set up as described in SECTION 5.2 in this report. The details of how to input the coordinate values are also found there.

When setting up this file the user needs to know how many bags are to be used with their relevant (x,y) coordinate values. The values must be stored one to a line as the program reads only the first value from each line of a data file. The first value must be the x-coordinate of the first bag and the second value must be the y-coordinate of the first bag and so on.

Q It is important not to include the value of the x-coordinate of the last bag. The program will automatically assign this value identical to the x-coordinate of the first bag. (See SECTION 3.2)

If these data are incorrect for a particular Bag Coordinate Set Up required whilst the program is being run then the incorrect data will be displayed but can be edited within the running program. This will not change the data file, that must be done outside of STABAG using any editing set up. It is important that this data file always be called COORD_x.DAT as that is what the program looks for. If this is not so then the program will fail.

ROOTF_x.DAT

This file is used to store the required root values for a load condition of the stabilator. Up to ten sets of root conditions data may be stored in external files and called by the program. There are only three values stored in each file; the root shear force, the root bending moment, and the root torsion. They are called when using the Root Conditions Set Up procedure, option '2' from the Main Menu. (See SECTION 5.3)

The values must be stored one to a line as the program reads only the first value from each line of a data file. If these data are incorrect for a particular Root Condition Set Up required whilst the program is being run then the incorrect data will be displayed but can be edited within the running program. This will not change the data file, that must be done outside of STABAG using any editor set up. It is important that this data file always be called ROOTF_x.DAT as that is what the program looks for. If this is not so then the program will fail.

FA18_x.DAT

This external data file is used to store the profiles of the shear/bending/torsion diagrams found from sources other than this program. Up to 10 sets of diagrams may be called from the program, naming each 'FA18_x.DAT' where 'x' is any integer in the range 0-9. On calling the file from the running program only the integer value need be inputted. (See SECTIONS 5.5 & 5.6)

Ten specific spanwise positions are stored in this data file for each set of diagrams. For each spanwise position there will be four values; the spanwise position, the shear force, the bending moment, and the torsion. The units used are inches(in), pound-force(lbf), inch-pound-force(in.lbf), and inch-pound-force(in.lbf) respectively. Note that the program automatically factors the input values x10000 for *lbf* and x100000 for *in.lbf*.

The ten specific spanwise positions (along the spindle axis) are from the root position as follows: 0,10,20,30,40,50,60,70,80,88 measured in inches (*in*). The 88in spanwise position is at the stabilator tip and the three load values (shear/bending/moment) should be zero.

The values must be stored one to a line as the program only reads the first value from each line of a data file. The order required is as follows: spanwise position, shear force, bending moment, and torsion, with all these values given in the outward spanwise order.

6. CONCLUSION

In preparation for a fatigue test on the F/A-18 rear empennage, a method has been developed to determine actuator loads for the horizontal stabilators. A computer program called STABAG has been written which implements the method to enable automated computation of actuator loads corresponding to input spectrum points.

The basic function of the program STABAG is to determine a set of point forces at prescribed locations on the stabilator which closely simulates prescribed spanwise distributions of shear force, bending moment, and torsion. As well, prescribed root values of these quantities are exactly generated.

The number and position of these point forces are specified by the user, as are the above mentioned root conditions. The spanwise distributions are selected from a data bank of load cases held in external files.

After the point forces are calculated, the corresponding shear force, bending moment, and torsion diagrams can be drawn and compared to other such diagrams, including those found from the distributions being simulated and from other sources read in from an external file.

A numerical comparison of shear force, bending moment, and torsion at the given point force positions can also be made, showing the percentage differences. This can be done between different calculated distributions or with other distributions read in from an external file.

The program STABAG has been written in Pascal using Borland Turbo Pascal version 5.5. This report describes the program and serves as an operating manual for it.

APPENDIX 1

Setting Up And Running STABAG

Hardware

The program STABAG is written using Borland Turbo Pascal requiring an IBM compatible PS/2 style personal computer. For any hardcopy requirements a printer is necessary and it is desirable to have a colour printer in order to make best use of the colour-coded screen output displays used in the program. (See SECTION 5.7)

Software

The program code has been written to suit Turbo Pascal versions 5 or 5.5. The following files are necessary to run STABAG:

Turbo files:	TURBO.EXE		
	TURBO.HLP		
	TURBO.TPL		
	TPL.EXE		
	GRAPH.TPU	*	
	EGAVGA.BGI	*	(CGA.BGI if using a CGA screen)
	TRIP.CHR	*	
	LITT.CHR	*	
STABAG files:	STABAG.PAS		
	COORD_x.DAT	*	(See SECTION 5.8)
	ROOTF_x.DAT	*	(" ")
	FA18_x.DAT	*	(" ")
	MANUAL.DOC		(This report)

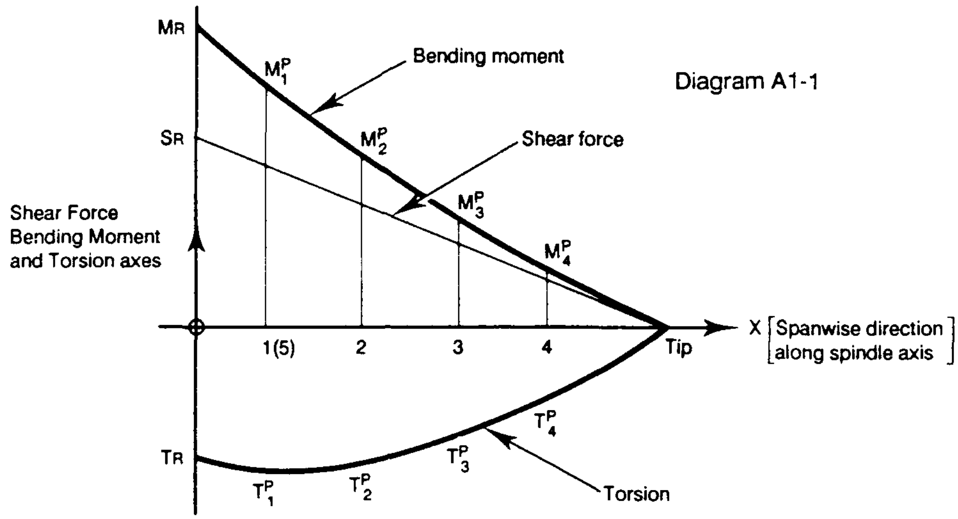
* Denotes the files that are required to be stored adjacent file STABAG.PAS when running the program.

To run STABAG for the first time the user must call STABAG.PAS from within Turbo Pascal and compile the program. Once this has been done, it is not necessary to run the program from within Turbo Pascal. Instead, providing Turbo Pascal is on the DOS path directory, STABAG can be run from wherever it is stored by typing "Stabag".

For a hardcopy of the code, stored as STABAG.PAS, it is possible to read it into any word processing program as a document and carry out the normal procedures for printing such a document. "WORD5" is capable of doing this very easily and is available at the Aeronautical Research Laboratory.

APPENDIX 2

Example Calculations of Stabilator Load Determination Scheme



Consider location #3: the bending and torque at location #3 are determined by the force F_4 at location #4.

$$M_3^A = F_4(x_4 - x_3)$$

$$T_3^A = F_4 y_4 \qquad \text{(just outboard of location \#3)}$$

Desirable values: M_3^P and $(T_3^P + T_4^P)/2$

Define error E3 $= \left(\dfrac{M_3^P - M_3^A}{M_3^P}\right)^2 + \left(\dfrac{(T_3^P + T_4^P)/2 - T_3^A}{(T_3^P + T_4^P)/2}\right)^2$

$$= \left(1 - \frac{M_3^A}{M_3^P}\right)^2 + \left(1 - \frac{2T_3^A}{T_3^P + T_4^P}\right)^2$$

$$= \left(1 - \frac{F_4}{M_3^P}(x_4 - x_3)\right)^2 + \left(1 - \frac{2F_4 y_4}{T_3^P + T_4^P}\right)^2$$

Now to minimise the error, the first differential of E3 with respect to F_4 is equated to zero and then solved for F_4.

$$\frac{dE3}{dF_4} = \frac{-2}{M_3^P}(x_4 - x_3)\left(1 - \frac{F_4}{M_3^P}(x_4 - x_3)\right) - \frac{4y_4}{T_3^P + T_4^P}\left(1 - \frac{2F_4 y_4}{T_3^P + T_4^P}\right) = 0$$

Giving

$$F_4 = \frac{(T_3^P+T_4^P)(x_4-x_3) + 2M_3^P y_4}{\dfrac{(T_3^P+T_4^P)(x_4-x_3)^2}{M_3^P} + \dfrac{4M_3^P y_4^2}{(T_3^P+T_4^P)}}$$

Now consider location #2:

$$M_2^A = F_4(x_4-x_2) + F_3(x_3-x_2)$$

$$T_2^A = F_4 y_4 + F_3 y_3 \qquad \text{(just outboard of location \#2)}$$

Desirable values: M_2^P and $(T_2^P+T_3^P)/2$

$$E2 = \left(1 - \frac{F_4(x_4-x_2)}{M_2^P} - \frac{F_3(x_3-x_2)}{M_2^P}\right)^2 + \left(1 - \frac{2F_4 y_4}{T_2^P+T_3^P} - \frac{2F_3 y_3}{T_2^P+T_3^P}\right)^2$$

And to minimise the error, the first differential of $E2$ with respect to F_3 is equated to zero and then solved for F_3.

$$\frac{dE2}{dF_3} = \frac{-2}{M_2^P}(x_3-x_2)\left(1 - \frac{F_4(x_4-x_2)}{M_2^P} - \frac{F_3(x_3-x_2)}{M_2^P}\right)$$

$$- \frac{4y_3}{T_2^P+T_3^P}\left(1 - \frac{2F_4 y_4}{T_2^P+T_3^P} - \frac{2F_3 y_3}{T_2^P+T_3^P}\right) = 0$$

Giving

$$F_3 = \frac{(T_2^P+T_3^P)(x_3-x_2) - \dfrac{(T_2^P+T_3^P)F_4(x_3-x_2)(x_4-x_2)}{M_2^P} + 2M_2^P y_3 - \dfrac{4M_2^P F_4 y_3 y_4}{(T_2^P+T_3^P)}}{\dfrac{(T_2^P+T_3^P)(x_3-x_2)^2}{M_2^P} + \dfrac{4M_2^P y_3^2}{(T_2^P+T_3^P)}}$$

The root shear, bending, torque for the stabilator are S_{root}, M_{root}, and T_{root} from the load profiles, but suppose values S_R, M_R, and T_R have been specified for these root conditions. We wish to match the specified values exactly.

$$S_R = F_1 + F_2 + F_3 + F_4 + F_5 \qquad (1)$$

$$M_R = F_1x_1 + F_2x_2 + F_3x_3 + F_4x_4 + F_5x_1 \qquad (2)$$

$$T_R = F_1y_1 + F_2y_2 + F_3y_3 + F_4y_4 + F_5y_5 \qquad (3)$$

F_5 is the extra bag-force at the same spanwise location as bag force #1

From (1);

$$F_1 + F_5 = (S_R - F_3 - F_4) - F_2$$

From (2);

$$F_1 + F_5 = \frac{(M_R - F_3x_3 - F_4x_4) - F_2x_2}{x_1}$$

Therefore;

$$x_1(S_R - F_3 - F_4) - x_1F_2 = (M_R - F_3x_3 - F_4x_4) - F_2x_2$$

$$F_2(x_2 - x_1) = (M_R - F_3x_3 - F_4x_4) - x_1(S_R - F_3 - F_4)$$

Giving

$$\mathbf{F_2 = \frac{(M_R - F_3x_3 - F_4x_4) - x_1(S_R - F_3 - F_4)}{x_2 - x_1}}$$

And from (1);

$$F_5 = (S_R - F_2 - F_3 - F_4) - F_1$$

Substituting this into (3) gives;

$$\mathbf{F_1 = \frac{T_R - S_Ry_5 - F_2(y_2 - y_5) - F_3(y_3 - y_5) - F_4(y_4 - y_5)}{y_1 - y_5}}$$

And

$$\mathbf{F_5 = S_R - F_1 - F_2 - F_3 - F_4}$$

APPENDIX 3

Screen Frames From A Typical Run Sequence

SEE OVER

F/A-18

Stabilator

Equivalent set of point–forces required
for pneumatic bag load case simulation

Hit any key for MAIN MENU . . .

MAIN MENU

0: EXIT
1: Input New Bag Coordinates
2: Input New Root Conditions
3: Calculate and Table Forces
4: Graph Shear, Bending, Torsion
5: Compare Shear, Bending, Torsion # 1

BAG COORDINATES SET-UP

```
Enter Bag Coordinate External File No. (COORD_x.DAT) x =          : 1

Input number of bags you wish to use                              : 5

Listed is the coordinates of the centre-points of these 5 bags.

 ( NOTE that the origin is the l.e. root position with positive    )
 ( "Y" aftwards and positive "X" towards the stabilator wing tip   )
 ( It is assumed that Bag#1 & Bag#5 have the same "X" co-ordinate. )

                 CHANGE bag number? (0=No, 1=Yes)                 : 0
```

BAG COORDINATES SET-UP

Enter Bag Coordinate External File No. (COORD_x.DAT) x = : 1

Input number of bags you wish to use : 5

Listed is the coordinates of the centre-points of these 5 bags.

(NOTE that the origin is the l.e. root position with positive)
(Y" aftwards and positive "X" towards the stabilator wing tip)
(It is assumed that Bag#1 & Bag#5 have the same "X" co-ordinate.)

BAG #	X (in)	Y (in)
1	13.00	43.10
2	31.00	59.00
3	49.00	74.90
4	67.00	90.80
5	13.00	60.00

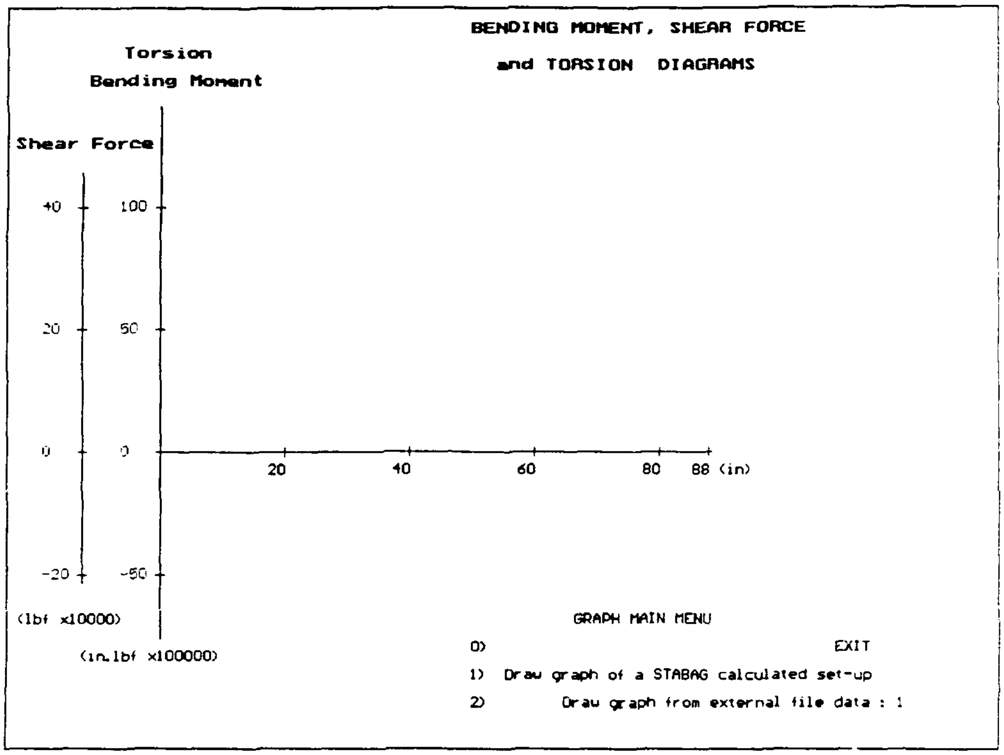
If the above table is CORRECT then enter <0>
If it is INCORRECT enter the Bag Number to be changed : 0

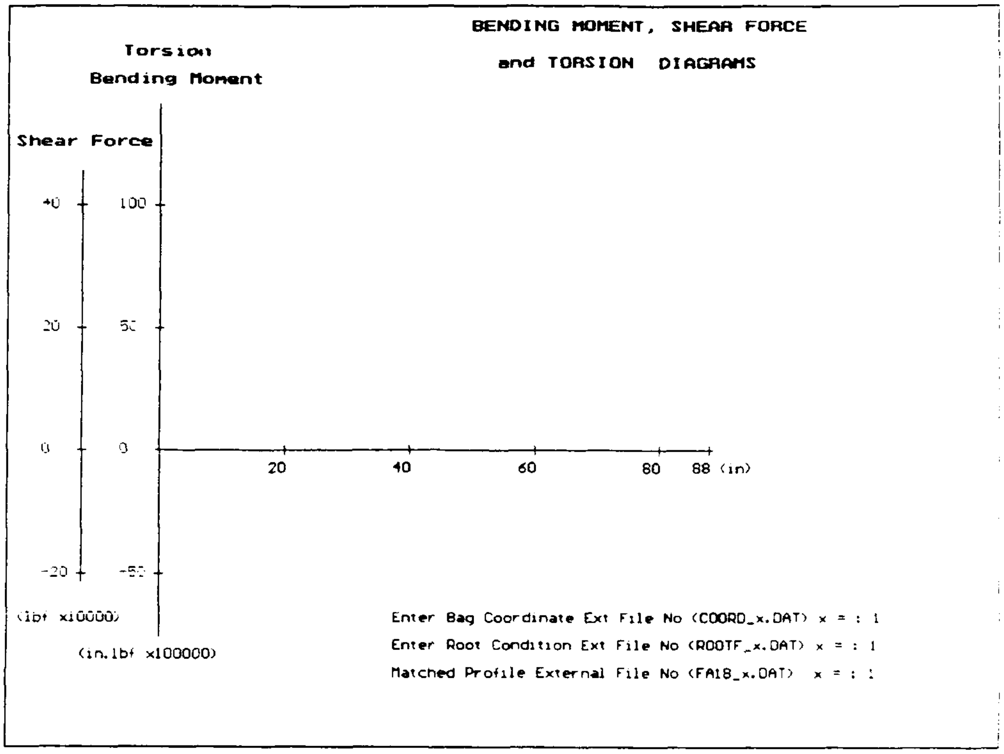
ROOT CONDITIONS SET-UP

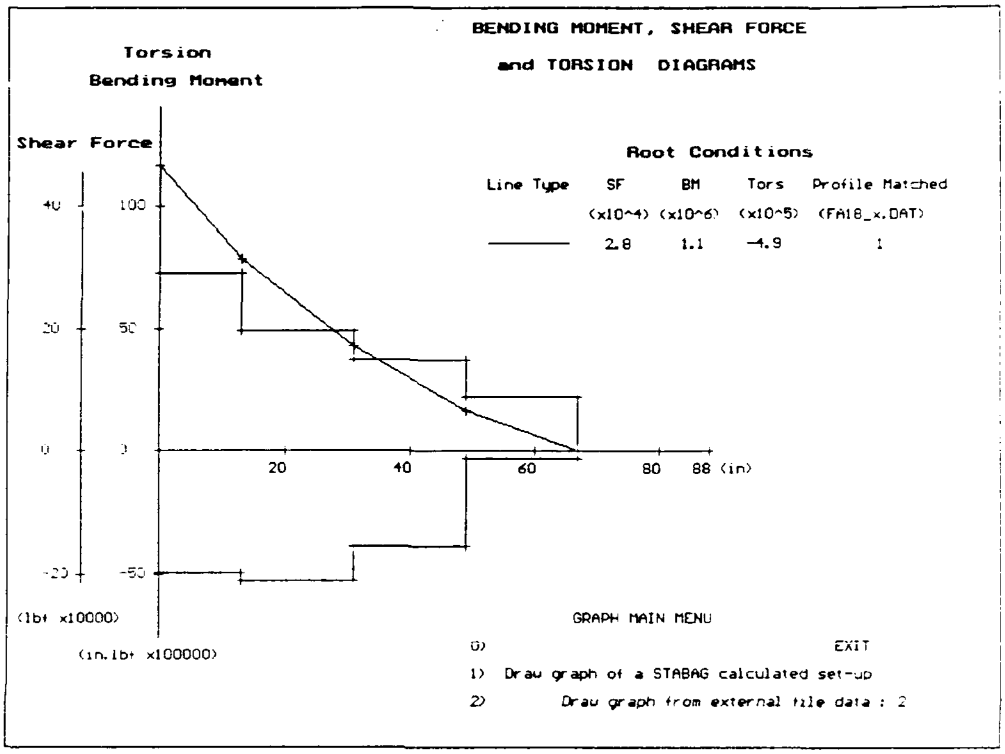
```
1) Enter Root Conditions External File No. (ROOTF_x.DAT)        x = : 1


2) Input Root SHEAR Force        (lbf)                                  : 28700
3) Input Root BENDING MOMENT     (in.lbf)                               : 1152000
4) Input Root TORSION            (in.lbf)                               : -490000


        Enter <0> for NO CHANGE or 1,2,3,4,5 for CHANGE                 : 0
```

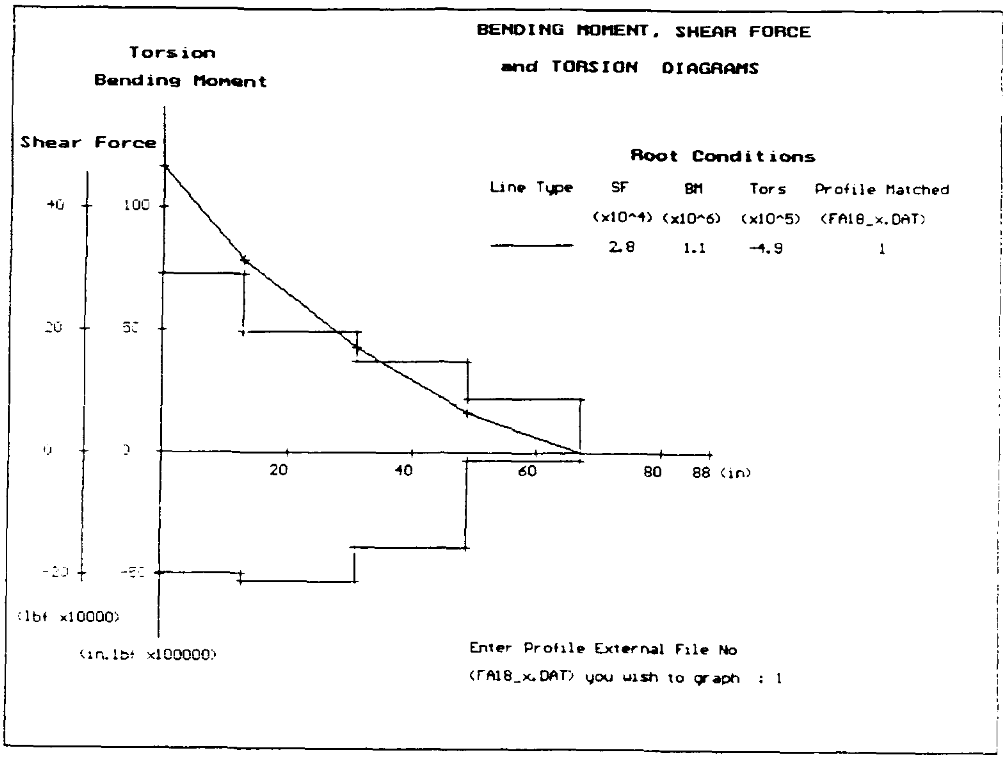
CALCULATION AND TABLE OF BAG-FORCES

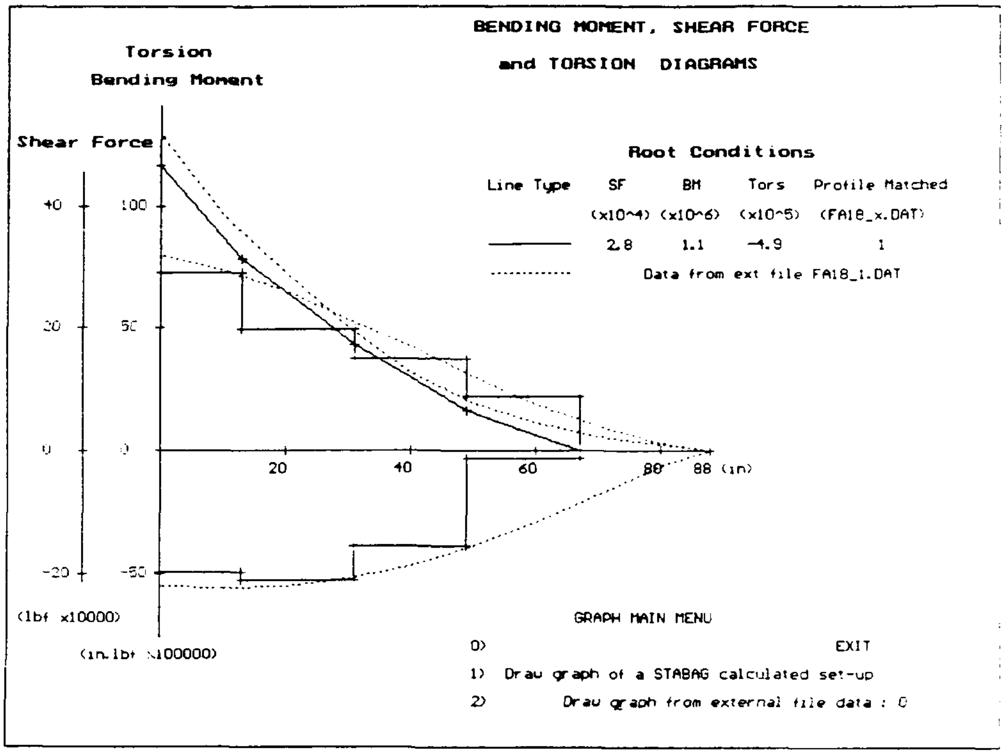
```
Enter Bag Coordinate External File No. (COORD_x.DAT)    x = : 1

Enter Root Condition External File No. (ROOTF_x.DAT)    x = : 1

Enter Profile External File No. to be used (FA18_x.DAT) x = : 1

                                 BAG FORCE (lbf)

Bag Coordinates Set-up #    1
Root Conditions Set-up #    1
 Profile Matched...
Ext File FA18_x.DAT; x =    1

             Bag #  1     6162.80
                    2     4708.29
                    3     6006.83
                    4     8850.09
                    5     2971.99

         List another set of bag-forces ? (Yes=1,No=0)      : 0
```


BENDING MOMENT, SHEAR FORCE
and TORSION DIAGRAMS
Torsion
Bending Moment
Shear Force
40
20
0
-20
100
50
0
-50
20
40
60
80
88 (in)
(lbf x10000)
(in.lbf x100000)
GRAPH MAIN MENU
0) EXIT
1) Draw graph of a STABAG calculated set-up
2) Draw graph from external file data : 1


BENDING MOMENT, SHEAR FORCE
and TORSION DIAGRAMS
Torsion
Bending Moment
Shear Force
40
20
0
-20
100
50
0
-50
20
40
60
80
88 (in)
(lbf x10000)
(in.lbf x100000)
Enter Bag Coordinate Ext File No (COORD_x.DAT) x = : 1
Enter Root Condition Ext File No (ROOTF_x.DAT) x = : 1
Matched Profile External File No (FA18_x.DAT) x = : 1


BENDING MOMENT, SHEAR FORCE
and TORSION DIAGRAMS
Torsion
Bending Moment
Shear Force
Root Conditions
Line Type SF BM Tors Profile Matched
(x10^4) (x10^6) (x10^5) (FA18_x.DAT)
2.8 1.1 -4.9 1
40 20 0 -20
100 50 0 -50
20 40 60 80 88 (in)
(lbf x10000)
(in.lbf x100000)
GRAPH MAIN MENU
0) EXIT
1) Draw graph of a STABAG calculated set-up
2) Draw graph from external file data : 2


BENDING MOMENT, SHEAR FORCE
and TORSION DIAGRAMS
Torsion
Bending Moment
Shear Force
Root Conditions
Line Type SF BM Tors Profile Matched
(x10^4) (x10^6) (x10^5) (FA18_x.DAT)
2.8 1.1 -4.9 1
40 100
20 50
0 0
-20 -50
20 40 60 80 88 (in)
(lbf x10000)
(in.lbf x100000)
Enter Profile External File No
(FA18_x.DAT) you wish to graph : 1


BENDING MOMENT, SHEAR FORCE
and TORSION DIAGRAMS
Torsion
Bending Moment
Shear Force
Root Conditions
Line Type SF BM Tors Profile Matched
(x10^4) (x10^6) (x10^5) (FA18_x.DAT)
2.8 1.1 -4.9 1
Data from ext file FA18_1.DAT
40 20 0 -20
100 50 0 -50
20 40 60 80 88 (in)
(lbf x10000)
(in.lbf x100000)
GRAPH MAIN MENU
0) EXIT
1) Draw graph of a STABAG calculated set-up
2) Draw graph from external file data : 0

COMPARISON OF SHEAR/BENDING/TORSION AT BAG LOCATIONS

Compare either - 1) STABAG Calculated Set-up
or - 2) Data From External File : 1

Bag #	Span Pos (in)	Shear Force (x10000 lbf)			Bending Moment (x100000 in.lbf)			Torsion		
		1st	2nd	%diff	1st	2nd	%diff	1st	2nd	%diff

COMPARISON OF SHEAR/BENDING/TORSION AT BAG LOCATIONS

```
Compare STABAG Calc"d Set-up; Bag Coordinates Ext File No (COORD_x.DAT) x = : 1
                              Root Conditions Ext File No (ROOTF_x.DAT) x = : 1
                              Matched Profile Ext File No (FA18_x.DAT)  x = : 1

With either  - 1) STABAG Calculated Set-up
         or  - 2)  Data From External File : 2
```

Bag #	Span Pos (in)	Shear Force (x10000 lbf)			Bending Moment (x100000 in.lbf)			Torsion		
		1st		%diff	1st	2nd	%diff	1st	2nd	%diff

COMPARISON OF SHEAR/BENDING/TORSION AT BAG LOCATIONS

Compare STABAG Calc"d Set-up; Bag Coordinates Ext File No (COORD_x.DAT) x = : 1
Root Conditions Ext File No (ROOTF_x.DAT) x = : 1
Matched Profile Ext File No (FA18_x.DAT) x = : 1

with Data From External File External File FA18_x.DAT x = : 1

Bag #	Span Pos (in)	Shear Force (x10000 lbf)			Bending Moment (x100000 in.lbf)			Torsion		
		1st	2nd	%diff	1st	2nd	%diff	1st	2nd	%diff
1 à 5	13.00	2.41	2.82	-14.3	7.79	8.88	-12.3	-5.04	-5.50	-8.2
2	31.00	1.72	2.07	-16.7	4.27	4.78	-10.7	-4.49	-5.07	-11.4
3	49.00	1.19	1.24	-4.3	1.59	2.04	-21.9	-2.07	-3.92	-47.2
4	67.00	0.44	0.51	-13.3	0.00	0.73	-100.0	-0.17	-2.10	-91.9

0) EXIT
1) Another comparison : 0

APPENDIX 4

Example External File Listings

FAIR_x.DAT

```
0
3.19
12.8
-5.44
10
2.92
9.60
-5.52
20
2.57
7.20
-5.44
30
2.11
4.96
-5.12
40
1.68
3.12
-4.64
50
1.19
1.92
-3.84
60
0.757
1.12
-2.88
70
0.405
0.56
-1.76
80
0.135
0.24
-0.64
88
0
0
0
```

COORD_x DAT

```
13.0
43.1
31.0
59.0
49.0
74.9
67.0
90.8
60.0
```

ROOTF_x.DAT

```
28700
1152000
-490000
```

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